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## METHOD FOR PLACING AND ATTACHING SOLDER BALLS TO SUBSTRATES

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### Background of the Invention

The present method used by industry for placing and attaching solder balls to ball grid array (BGA) packages produces unacceptable production yields. The pad surface is coated with flux and the balls are placed into position on the package. As the flux dries, the balls become stuck to the pad surfaces. The assemblies are placed on a conveyor and the balls are reflow soldered to the BGA pads. As the assemblies heat-up during the reflow process, the flux is liquefied and the bonds between the balls and pads are destroyed. As a result, the balls are free to move during the rigors of transport through the furnace. Defects such as vacancies, bridging of adjacent balls and loss of positional accuracy are created. Also, flux residues are trapped between the pads and the underside surfaces of the balls and may be difficult to completely remove. These uncleaned residues may, depending on the type of flux used, cause high resistance shorts and/or corrosion subsequent to final assembly soldering operations. U.S. Patent Nos. 5,499,487 and 5,551,216, both of which are incorporated herein by reference, disclose methods and devices for the placement of solder balls on BGA packages.

The demand for BGA devices has steadily increased, and more efficient high volume manufacturing assembly methods need to be developed to keep pace. Production yields also need to be improved so that the cost of manufacturing can be reduced. Accordingly, there is a need for a new and more cost effective method of placing and attaching solder balls to BGA packages.

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### Summary of the Invention

A new and improved method of and apparatus for placing and attaching solder balls in a predetermined pattern to substrates, e.g., BGA packages, has been developed that eliminates all the problems associated with the current method. The method comprises first providing a carrier for the substrate. The substrate is inserted into the carrier and an alignment plate comprising a plurality of through-holes is positioned above the substrate and spaced apart from the substrate a distance less than the diameter of the solder balls and preferably less than about half of the diameter of the solder balls. For example, if the diameter of the solder balls is 0.005 inch, the spacing between the carrier and the alignment plate is preferably from about 0.001 inch

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1 to about 0.002 inch. The pattern of the through-holes corresponds to the predetermined pattern in which the solder balls will be attached to the substrate.

5 A solder ball is then inserted into each hole of the alignment plate whereby the solder balls drop into contact with the substrate, the alignment plate maintaining the solder balls in the predetermined pattern. The alignment plate and substrate are then heated sufficiently to melt at least the surface of the solder balls, the alignment plate and substrate are then cooled to resolidify the solder balls which bond to the substrate in the predetermined pattern. The alignment plate is then removed and the substrate is removed from the holder.

10 The substrate may be any substrate on which solder balls may be attached. Examples of substrates include BGA packages, mini and micro BGA packages, flip chips, wafer scale flip chips, micro-electromechanical systems (MEMS) interconnects and the like.

15 The carrier and alignment plates are preferably made of graphite, but may be made of any other suitable material such as ceramic, aluminum oxide and the like. It is preferred that the alignment plate be made of a material that is not wetted by or adhered to by the melted solder balls.

20 The solder balls may be made of the same material throughout or may have, for example, a core of a higher melting temperature material and an outer shell of a lower melting temperature material. Both types are commercially available and are well known in the art. For example, suitable solder balls are available from Alpha Metals Inc. of New Jersey and are described in Alpha Metals Inc.'s Technical Bulletins SM-480 through SM-487, and Application Bulletins SM-487 through SM-490 and SM-473-1, all of which are incorporated herein by reference. Any size solder balls may be used. Preferred sizes include diameters of 0.002 inch and up.

25 The solder balls may be inserted into the holes of the alignment plate by any suitable method. A presently preferred method is to provide a vacuum loader plate which includes a loader plate having a plurality of holes in the same pattern as that of the alignment plate. The holes of the loader plate however are smaller in diameter than that of the solder balls. Solder balls are loaded onto the loader plate, a portion of a ball extending into each hole. A vacuum is then generated which holds the balls in the holes. The loader plate is then positioned over the alignment plate, the holes of the loader plate being aligned with the holes of the alignment plate.  
30 When the vacuum is released, the balls fall into the holes of the alignment plate and drop down into contact with the substrate.

35 Preferably the substrate and alignment plate are heated for a time and at a temperature and reduced pressure, e.g. 1 torr to 1 millitorr, and in an appropriate atmosphere, e.g., in the presence of a forming gas such as hydrogen and nitrogen, sufficient to remove at least a portion of and preferably all of any oxides existing on the surface of the solder balls. Thereafter, the

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1 substrate and alignment plate are heated for a time and at a temperature and pressure and in an appropriate atmosphere, e.g., nitrogen, sufficient to at least partially melt the solder balls so that solder flows onto the conductive pads of the substrate.

5 Heating may be accomplished by any suitable method. A presently preferred method comprises electrically connecting the carrier and alignment plates to electrodes and passing an electrical current through the plates. Because of the electrical resistance of the graphite, the temperature of these plates and the substrate rises rapidly. Rather than heating by electrical resistance, the plates may be placed, for example, on a hot plate or on an adjacent or some other appropriate heating element.

10 The invention further comprises an apparatus for attaching solder balls to a substrate in a predetermined pattern. The apparatus comprises a carrier for the substrate and an alignment plate which comprises a plurality of through-holes in a pattern which corresponds to the predetermined pattern. Means for inserting a solder ball into each of the through-holes of the alignment plate is provided. Means for heating the alignment plate and substrate to a  
15 temperature sufficient to melt at least the surface of the solder balls is also provided.

A preferred means for inserting a solder ball into each hole of the alignment plate comprises a vacuum loader plate assembly which comprises a loader plate having the same corresponding hole pattern as does the alignment plate, the holes on the loader plate being smaller than the diameter of the solder balls. The solder balls are loaded onto the loader plate and released into the holes of the alignment plate as described above.  
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If desired, the vacuum loader plate assembly and alignment plate could be combined into a single structure. In such an embodiment, on the side of the loader plate on which the solder balls are loaded, the through-holes are enlarged to a diameter slightly larger than the diameter of the solder balls to form cups for receiving the solder balls, e.g., as shown in FIG. 18. After  
25 the loader plate is loaded, a vacuum is established to maintain the balls in the cups and the loader plate is positioned directly over the substrate as described previously with respect to the alignment plate. The vacuum is then released and the balls fall into contact with the substrate being maintained in position by the cups of the loader plate. Thereafter the loader plate and substrate are heated and cooled to bond the solder balls to the substrate. In such an embodiment,  
30 the loader plate is preferably made of graphite or other suitable material to which the solder will not adhere.

By using the method of the present invention, solder ball interconnects (solder bumps) are formed on the substrate which have improved coplanarity, i.e., uniformity in height, and improved accuracy in pitch, i.e., spacing. Preferably the variance in coplanarity among the  
35 solder ball interconnects is less than 10%, more preferably less than 5% of the average height

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1 of the solder ball interconnects. The solder ball interconnects which are formed have a unique shape, with a generally spherical head region and a curved or radiused neck region adjacent the surface of the substrate, the minimum diameter of the neck region being smaller than the largest diameter of the head regions generally as shown in FIG. 19.

5 In a particularly preferred embodiment, BGA packages are placed in a holder or carrier in an up-side-down position. A top or alignment plate is placed and fixed on the carrier. The top plate has a through-hole pattern that corresponds to the pad pattern on the BGA packages. The hole diameter is slightly larger than the ball diameter. Balls are automatically loaded into the holes (one ball per hole). Since the top plate is fixed to the carrier, the hole walls prevent the balls from moving. The balls contact the pad surfaces while being precisely fixed in the required position. The top plate/carrier assembly is automatically placed on a graphite platen inside a chamber. The chamber lid is closed. The chamber is back filled with forming gas or inert gas and an electrical current is passed through the platen. The graphite material serves as a resistance heater and heat is rapidly generated and thermally conducted into the plate/carrier assemblies. In a manner of a few minutes, the chamber load is heated to the soldering temperature whereupon the outer solder coating of the balls melts, forming a ball/pad joint or bond. The soldering operation is accomplished without the use of flux. In this way, post solder cleaning is not required.

20 The present process is capable of high volume production and extremely high yields. As an example, 3,300 chip scale BGA's can be processed per load. This equates to approximately 19,800 parts per hour. The process will accommodate any package size and ball diameters of .005 - .035 inches. Since the parts are fixed during processing, vacancies, bridging and positional defects are totally avoided. Defects associated with flux are also totally avoided since the process is a fluxless operation.

25 The process utilizes specially designed tooling for loading and holding the packages and balls in the required position during processing. The process can be utilized for both ceramic and plastic BGA packages. The method of the present invention includes ball attachment for plastic packages and die attach, lid seal and ball attach for ceramic packages. The soldering operation is performed without flux in a controlled atmosphere. The time required for soldering (loading of chamber, heat-up period, dwell time, and cool-down period) is typically 10 minutes or less.

30 Equipment is available for engineering prototype and low volume production as well as very high volume applications. As an example of high volume capability, 3,300 chip scale BGA packages can be processed per furnace load. This equates to approximately 19,800 parts per

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- 1 hour. The method of the present invention will accommodate all package sizes and any ball diameter. Preferred ball diameters are within the inclusive range of .005 - .035 inches.

#### **Brief Description of the Drawings**

- 5 FIG. 1 is a typical boat design for the low volume ball attach method.  
FIG. 2 is a typical alignment plate design for the boat shown in FIG. 1.  
FIG. 3 is a typical vacuum loader plate design for the hole pattern shown in FIGS. 1 and 2.  
FIG. 4 is a typical ball attach soldering profile for 635n/37Pb solder material.  
10 FIG. 5 are two fully loaded holding frames positioned end to end.  
FIG. 6 is a typical carrier plate design for the high volume method of ball attach.  
FIG. 7 is a typical alignment plate design for the high volume ball attach method.  
FIG. 8 is a typical multipurpose boat design for ceramic BGA packages.  
FIG. 9 is a typical die attach soldering profile for 80Au/20Sn solder material.  
15 FIG. 10 is a typical multipurpose heat plate design for the low volume method of lid seal and ball attach.  
FIG. 11 is a typical lid seal soldering profile for 80Au/20Sn solder material.  
FIG. 12 is a typical multipurpose carrier plate design for ceramic BGA packages.  
FIG. 13 is a lid seal plate design for ceramic BGA packages.  
20 FIG. 14 is a handling frame that is fully loaded with multipurpose carrier assemblies and cross sectioned in the plane referenced in FIG. 5.  
FIG. 15 is a schematic of typical controlled atmosphere furnace, vacuum.  
FIG. 16 is a cut away cross sectioned view showing the relationship of the vacuum loader plate; and alignment plate with a solder ball loaded onto the loader plate.  
25 FIG. 17 is a cut away cross sectioned view showing a solder ball in contact with the substrate and held in place by the alignment plate.  
FIG. 18 is a cut away cross sectioned view showing another embodiment of the invention wherein the loader plate and alignment plate are combined.  
FIG. 19 is a side view of a solder ball interconnect (solder bump) formed by the present  
30 invention.

#### **Description of the Preferred Embodiments**

1. Low Volume Method for Attaching Balls to BGA Packages  
Low volume ball attachment is performed in a controlled atmosphere furnace, such as the  
35 DAP-2200 furnace commercially available from Scientific Sealing Technology, a division of

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- 1 EDM Supplies, Inc., of Downey, California. The DAP-2200 furnace is described, for example,  
in the publication Reliable and Economical Assembly of Hybrid Microelectronic Packages by  
M. Denlinger and the brochure Hermetic Package Sealing and Assembly - Model DAP-2200,  
both available from Scientific Sealing Technology, and both incorporated herein by reference.
- 5 The tooling for the furnace is composed of two plates machined from graphite material. The  
bottom plate or boat (also referred to as the carrier plate or holder) is specially machined with  
cavities to accept the packages (Figure 1). The cavity size and depth is slightly greater than that  
of the package size and thickness respectively. The top plate or alignment plate consists of a  
drilled hole pattern that corresponds exactly to the specific pad pattern of the BGA package. One  
10 complete hole pattern is drilled for each corresponding cavity in the boat (Figure 2). The holes  
are slightly larger than the diameter of the solder balls. For example, if the solder balls are 0.010  
inch, the holes are preferably about 0.011 inch. A chamfered surface is provided at the top of  
the holes for receiving the solder balls from the vacuum holder plate (discussed below). Dowel  
pins are inserted into the boat and are allowed to protrude above the plane of the top surface.
- 15 The boat cavities are loaded with BGA packages and the alignment plate is made to mate with  
the boat by way of the dowel pins.

The solder balls are loaded into the alignment plate using a vacuum loader assembly. The  
vacuum loader plate detail has the same corresponding hole pattern as does the alignment plate.  
However, the cross sectioned geometry of the vacuum loader plate holes is not the same as the  
alignment plate holes (Figure 3). The holes in the outside surface of the vacuum loader plate  
20 have a diameter slightly smaller than the ball diameter and are drilled to such a depth that, when  
balls are inserted, they protrude above the plane of the outside surface of the vacuum loader  
plate. Alternatively, the portion of the holes adjacent the surface of the loader plate may form  
a cup having a diameter slightly larger than the diameter of the solder balls, but a depth less than  
the diameter of the solder balls so the solder balls protrude from the surface of the loader plate  
25 as shown in FIG. 16. When a vacuum is generated in the cavity of the vacuum loader plate, balls  
are pulled into the holes and made fast to the plate by the force of the vacuum. Excess balls are  
brushed off and the vacuum loader plate is joined to the top alignment plate by way of dowel  
pins. The vacuum is released and the balls fall by gravity into the alignment plate holes. If  
30 desired, the loader can be backfilled with gas to a pressure sufficient to urge the solder balls  
away from the loader plate into the holes of the alignment plate. As a result, the balls are  
precisely located on the BGA pads and are restrained by the walls of the alignment plate holes  
(FIG. 17).

The tooling is placed on the electrodes inside the chamber of the furnace (FIG. 16). The  
35 solder profile (e.g, Figure 4) is programmed into the memory of the furnace microprocessor. The

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1 lid of the chamber is closed and the air withdrawn preferably to a pressure in the range of about  
1 torr to 1 millitorr. The chamber is then backfilled with nitrogen or other inert gas to a pressure  
of about 10 psig. The chamber is again evacuated to a pressure of from about 1 torr to about  
5 1 millitorr and an electrical current is passed through the tooling. Since the graphite material of  
the boat and alignment plates is a poor electrical conductor, the tooling is rapidly heated. The  
temperature is raised to 160°C and maintained 3 minutes in a vacuum atmosphere which helps  
to remove oxides on the surface of the solder balls. Thereafter the chamber is filled with forming  
gas (10% hydrogen and 90% nitrogen) to a pressure of about 1 to 4 psig and the temperature is  
raised to about 225°C and held for about two minutes. This is sufficient for the outside solder  
10 coating of the balls to melt and wick onto the joints around the area of contact between the balls  
and pads. Upon cooling, the solder balls are bonded to the BGA pads in the shape shown in  
FIG. 19. Thereafter tooling is removed from the chamber and the parts removed from the  
tooling. Since the soldering process is a fluxless operation, post solder cleaning is not required.

## 2. High Volume Method for Attaching Balls to BGA Packages

15 A preferred method for high volume ball attachment is similar to that used for low  
volume production in that the substrates, e.g., BGA packages, are processed in machined  
cavities and the balls are located with an alignment plate. The high volume method utilizes a  
large format controlled atmosphere furnace. Three graphite platens are contained inside the large  
format chamber. The platens are the heat generating medium. Many carrier assemblies are  
20 placed on each platen. Prior to heating, the carrier assemblies for each platen are mounted  
together in a holding frame (Figure 5). In this way, platen groups are handled as a single unit  
and the process is made more efficient.

A typical carrier plate design is shown in Figure 6 and the mating alignment plate design  
is illustrated in Figure 7. The alignment plate is made to mate with the carrier plate by way of  
25 dowel pins. The through-hole pattern of the alignment plate exactly corresponds to the pad  
pattern of the substrate. In this way, the alignment plate holes are precisely centered over the  
pads. One ball is inserted into each alignment plate hole using the previously described vacuum  
loader equipment. The carrier assemblies are then loaded into the holding frames and placed on  
the platens inside the chamber.

30 The large format chamber is evacuated and backfilled with an inert gas and the  
assemblies are automatically processed per the required profile such as that shown in Figure 4.  
Literally thousands of substrates can be processed in a single load. The actual number is  
dependent upon the size of the substrate.

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1     3.     Method for Low Volume Assembly of Ceramic BGA Packages

It is usually required that the die and lid details of ceramic BGA packages be attached with solder material. In this way, hermetic and thermal properties are optimized. The present methods for ball attach can be added to the existing expertise for void free flux free die attach and lid seal of ceramic packages.

5     A controlled atmosphere furnace, e.g., the DAP-2200 furnace, is used for low volume applications. As previously discussed, the graphite plate that contains the cavities (boat) is also the heat generating medium. A typical multipurpose boat design is shown in Figure 8. The cavities are machined to a depth equal to the thickness of the ceramic package. The ball location  
10     hole pattern is drilled through the cavity to the opposite side of the boat. The ceramic packages are loaded into the cavities open-end-up. Graphite inserts may be used to locate the solder preforms and die. The inserts are placed inside the packages and the solder preforms and die are dropped through open holes in the inserts. The boat is placed inside the furnace chamber and, as before, the chamber is evacuated and backfilled with an inert gas. The BGA packages are  
15     automatically processed per a predetermined profile. A typical die attach profile is shown in Figure 9. The boat now moves to the wire bonder and the wire bonds are made inside the packages.

A typical multipurpose heat plate configuration is shown in Figure 10. The open holes in the heat plate are exactly centered over the boat cavities. Lid details, with preforms attached,  
20     are dropped through the open holes onto the packages. The lids cannot move for they are captured by the walls of the open holes. The boat assembly is placed back into the furnace chamber and the packages are automatically solder sealed in a dry inert gas atmosphere per the prescribed profile. A typical lid seal profile is shown in Figure 11.

The boat assembly is removed from the chamber and flipped over so that the outside  
25     surface of the boat is right-side-up. The packages cannot fall out since they are captured inside the boat assembly. Balls are inserted into the ball locating holes of the boat (see Figure 8) using the previously described vacuum loader equipment. The boat assembly is again placed into the furnace chamber and the balls are attached per the applicable profile such as that shown in Figure 4. The completed BGA assemblies are removed from the boat assembly and electrically tested  
30     per the applicable requirements.

4.     Method for High Volume Assembly of Ceramic BGA Packages

Typical high volume carrier and lid seal plate designs are shown in Figures 12 and 13 respectively. The carrier cavity configuration is identical to the boat cavity configuration of the low volume ceramic package method. The carrier ball locating hole pattern is also the same.

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1           The ceramic BGA packages, inserts, solder preforms and die are all assembled using  
pick-and-place equipment. First, the packages are loaded into the carrier cavities and then the  
inserts are placed into the packages. The solder preforms and die are dropped through the open  
5           holes in the inserts. The fully loaded carriers are mounted into the holding frames (Figure 14)  
of the previously described large format equipment. The packages are automatically processed  
per the required die attach profile such as that shown in Figure 9. The carriers are released from  
the holding frames and the inserts are removed from the packages. The wire bonding operation  
is performed while the packages are positioned in the carrier plates.

10           The lid seal plates (Figure 13) are joined to the carriers by way of dowel pins and the lids,  
with preforms attached, are dropped through the open holes of the lid seal plates. The carrier  
assemblies are once again mounted into the holding frames and the packages are processed per  
the applicable lid sealing profile such as that shown in Figure 11.

15           Once the carrier assemblies are removed from the large format chamber, they are flipped  
over so that the ball locating hole pattern of the carriers is in the right-side-up position. Balls are  
inserted into the ball locating holes using the previously described vacuum loader equipment.  
The carrier assemblies are placed back in the holding frames and the BGA assemblies are  
processed per the applicable ball attach profile such as that shown in Figure 4.

#### 5.     Summary

20           Both the low and high volume methods produce substrate assemblies, e.g., BGA  
assemblies, of unequaled quality. The balls are precisely located in the required position, and  
the solder joints are free of the defects that are commonly associated with the current method  
(i.e., vacancies, bridging of adjacent balls, loss of positional accuracy, etc.). As a result,  
production yields are greatly improved. Since all soldering operations are performed without  
flux, post solder cleaning is not required.

25           The graphite tooling can be designed so that it can be used for multiple operations (e.g.,  
die attach, lid seal and ball attach). Supplemental pieces are added as required to satisfy the  
specific objectives of a given operation, but the same basic tooling can be used for all soldering  
operations. In this way, tooling cost is minimized. Moreover, the cost of assembly is  
significantly reduced since valuable time is not wasted transferring parts from one piece of  
30           specialized single-purpose tooling to another.

35           The high volume methods are capable of processing a large number of parts in a very  
short period of time. Assembly operations can be further optimized by incorporating pick-and-  
place equipment wherever feasible. These new cost effective methods described herein  
maximize productivity while maintaining a high level of quality.